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In electromagnetic signal processing, we computed Cramer-Rao bounds and ambiguity functions for estimating range, velocity, and direction using an active radar array. We derived bounds on the mean-square error for estimating vector systems, and analyzed the performance breakdown of subspace-based methods. We proposed methods for target tracking and interference cancellation using EM vector-sensor antennas; we also designed such an antenna of compact shape. We developed methods for fading channel estimation and symbol detection in unknown spatially correlated noise, and finite-length multi-input multi-output (MIMO) adaptive equalization. We also considered the equalization of a channel with discrete multi-tone (DMT) systems and insufficient cyclic prefix. We developed techniques for detecting rhe wake of a ship using an airborn SQUID magnetic transducer. In acoustics, we analyzed the effects of palacements of acoustic vector sensors (AVS's) on the performance of direction finding. We developed methods for direction finding with an AVS array near a reflecting boundary, and fast wide-band methods for finding the 3D position of a target. We computed expressions for the cross-correlations between wide-band noise components of an AVS, and developed a noise-reduction algorithm for dual-microphone systems useful for hearing aids. We proposed procedures for detecting expolosives with chemical sensing, such as automatic landmine detection and localization using chemical sensor array processing and statistical hypothesis testing. In biomedical applications, we estimated parameters of electrical source in the brain, including their location and moments, using EEG and MEG sensor arrays.

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Abstract

In electromagnetic signal processing, we computed Cramér-Rao bounds and ambiguity functions for estimating range, velocity, and direction using an active radar array. We derived bounds on the mean-square error for estimating vector systems, and analyzed the performance breakdown of subspace-based methods. We proposed methods for target tracking and interference cancellation using EM vector-sensor antennas; we also designed such an antenna of compact shape. We developed techniques for feature extraction and classification of hyperspectral data. In antenna arrays for communications, we developed methods for fading channel estimation and symbol detection in unknown spatially correlated noise, and finite-length multi-input multi-output (MIMO) adaptive equalization. We also considered the equalization of a channel with discrete multi-tone (DMT) systems and insufficient cyclic prefix. We developed techniques for detecting the wake of a ship using an airborne SQUID magnetic transducer. In acoustics, we analyzed the effects of placements of acoustic vector sensors (AVS's) on the performance of direction finding. We developed methods for direction finding with an AVS array near a reflecting boundary, and fast wide-band methods for finding the 3D position of a target. We computed expressions for the cross-correlations between wide-band noise components of an AVS, and developed a noise-reduction algorithm for dual-microphone systems useful for hearing aids. We proposed procedures for detecting explosives with chemical sensing, such as automatic landmine detection and localization using chemical sensor array processing and statistical hypothesis testing. In biomedical applications, we estimated parameters of electrical (dipole) sources in the brain, including their locations and moments, using EEG and MEG sensor arrays. We designed techniques for estimating mechanical properties (stiffness) of the heart wall using tagged-MRI, and current density in the heart using ECG/MCG sensor arrays. Our work has resulted in several successful transitions.

Electromagnetic Array Processing for Radar:

In [1], [2], we derived Cramér-Rao bound (CRB) expressions for the range (time delay), velocity (Doppler shift), and direction of a point target using an active radar or sonar array. First, general CRB expressions were derived for an arbitrary signal waveform and a noise model that allows both spatial and temporal correlation. We discussed the relationship between the CRB and ambiguity function for this model. Then we specialized our CRB results to temporally uncorrelated noise and the practically important signal shape of a linear frequency modulated (chirp) pulse sequence. We computed the CRB for a 3-dimensional array with isotropic sensors in spatially uncorrelated noise and showed that it is a function of the array geometry only through the "moments of inertia" of the array. The volume of the confidence region for the target's location was proposed as a measure of accuracy. For this measure, we showed that the highest (and lowest) target location accuracy is achieved if the target lies along one of the principal axes of inertia of the array. We compared the location accuracies of several array geometries, and illustrated how our results are used to optimally design radar array systems, including choosing optimal configurations and signals. We presented numerical examples for the TechSat21 system, see also the part of transitions below.

We presented in [3] maximum likelihood (ML) methods for estimating the parameters in the above problem, i.e. range, velocity, and direction of a point target, with a radar array in spatially correlated noise with unknown covariance. We considered structured and unstructured array response models, the latter being a means to achieve robustness and computational simplicity,

In [4], [5] we proposed a unified framework for the analysis of estimators of geometrical vector quantities and vector systems, through a collection of performance measures. Unlike standard performance indicators, these measures have intuitive geometrical and physical interpretations, are independent of the coordinate reference frame, and are applicable to arbitrary parameterizations of the unknown vector or system of vectors. For each measure we derived both finite-sample and asymptotic lower bounds that hold for large classes of

estimators and serve as benchmarks for the assessment of estimation algorithms. Like the performance measures themselves, these bounds are independent of the reference coordinate frame and we discussed their use as radar and sonar system design criteria.

The performance breakdown of subspace-based parameter estimation methods can be naturally related to a switch of vectors between the estimated signal and noise subspaces (a "subspace swap"). In [6] we derived a lower bound for the probability of such an occurrence and use it to obtain a simple data-based indicator of whether or not the probability of a performance breakdown is significant. We also presented a conceptually simple technique to determine from the data whether or not a subspace swap has actually occurred, and to extend the range of SNR values or data samples in which a given subspace method produces accurate estimates.

We introduced the use of several advanced sensors to signal processing. By incorporating novel sensor technologies and measurement models that make full use of the physical information available, we have added a new dimension to signal processing and considerably enhanced its practical utility for Air Force applications.

Our main original results on electromagnetic vector-sensor processing have appeared in a book chapter [7]. We introduced the concept of EM *vector sensors*, which measure the complete EM field at a single point, to the signal processing community. Such sensors are now commercially available. Using these sensors, we created methods for estimating the directions of arrival and polarization states of electromagnetic waves. To analyze their performance, we defined quality measures for estimating direction and orientation in 3D space, including mean-square angular error and covariance of vector-angular error, and derived lower bounds on them. These quality measures and bounds are not limited to EM waves and are already used by researchers in various fields. We conducted identifiability analyses that showed that with one vector sensor it is possible to find the directions and polarization ellipses of up to 3 sources. Thus, we determined that with one vector sensor it is possible to do what historically was done by an array of distributed scalar sensors. Furthermore, we showed that a vector sensor can resolve co-incident and very closely spaced sources based on polarization

differences. This can be of considerable benefit. For example, in cellular communications it provides a new multiple access diversity mechanism for increasing base station capacity. We also proposed a very fast algorithm for finding the source direction and analyzed its asymptotic statistical performance. A patent has been awarded for this algorithm.

In [8] we developed two high-resolution methods for direction-of-arrival estimation with electromagnetic vector sensors. Both methods, of which the first is ESPRIT-based and the second MUSIC-based, are applicable to scenarios where completely polarized and incompletely polarized signals co-exist. The ESPRIT-based method is computationally efficient, but there must be three vector sensors with a specific sensor arrangement in order to apply the method. On the other hand, the MUSIC-based method, although involving more computations, can work without the constraint that the ESPRIT-based method faces. In addition, neither method requires *a priori* information regarding the numbers of completely polarized and incompletely polarized signals impinging on the array, and will inherently provide such information.

In [9], [10] we presented two adaptive cross-product algorithms for tracking the direction to a moving source using an electromagnetic vector sensor. The first was a cross-product algorithm with a forgetting factor, for which we analyzed the performance and derived an asymptotic expression of the variance of angular estimation error. We found the optimal forgetting factor that minimizes this variance. The second was a Kalman filter combined with the cross-product algorithm, which is applicable when the angular acceleration of the source is approximately constant.

We developed in [11], [12] a beamformer employing a single electromagnetic vector sensor. This beamformer is of minimum-noise-variance type, and is used for interference rejection. It creates a beam focused in both direction and polarization that minimizes interference from undesired sources (e.g. jammers). In this way it can do the work of multiple scalar polarization-selective sensors.

We considered two types of signals: one carrying a single message, and the other carrying two independent messages simultaneously. The state of polarization of the interferences under

consideration ranged from completely polarized to unpolarized. To analyze the performance, we first obtained explicit expressions for the signal to interference-plus-noise ratio (SINR) in terms of the parameters of the desired signal, interference, and noise. Then we discussed some physical implications associated with the SINR expressions. Our SINR results provide a basis for effective interference suppression, as well as generation of dual-message signals in which there is minimum crosstalk.

The key advantages of our beamformer over current systems are that it:

- Works in three dimensions using only a single vector sensor, significantly simplifying receiver design and occupying very little space. Most current methods require a two-dimensional array to implement three-dimensional focusing.
- Exploits any polarization properties that the incoming signal may have. This provides a crucial criterion for distinguishing and isolating signals that may otherwise overlap too much for conventional systems.
- Extends easily to multiple sources with diverse carrier frequencies and polarizations, using multiple vector sensors as receivers.
- Distinguishes between sources without ambiguities, since it searches in both the polarization and direction domains. Existing methods suffer from frequency/localization ambiguities as they use only time delay information.

Numerical examples confirmed our analytical results.

In [13], [14] we proposed an approach to localize multiple sources based on spatially distributed electric and magnetic component sensors. By jointly exploiting all available electromagnetic information as well as spatial diversity (time delays), this approach should outperform both a single vector-sensor and scalar-sensor arrays in accuracy of direction of arrival estimation.

In [15], [16] we presented a structure for adaptively separating, enhancing and tracking uncorrelated sources with an electromagnetic vector sensor. The structure consists of a set

of parallel spatial processors, one for each individual source. Two stages of processing are involved in each spatial processor. The first preprocessing stage rejects all other sources except the one of interest, while the second stage is an adaptive one for maximizing the SNR and tracking the desired source. The preprocessings are designed using the latest source parameter estimates obtained from the source trackers, and a re-design is activated periodically or whenever any source has been detected by the source trackers to have made significant movement. Compared with conventional adaptive beamforming, the algorithm has the advantage that it is a "blind" scheme where no a priori information on any desired signal location is needed, the sources are separated at maximum SNR, and their locations are available. The structure is also well suited for parallel implementation. Numerical examples are included to illustrate the capability and performance of the algorithm.

In [17] we designed a compact vector-sensing antenna that consists of 3 co-located orthogonal doubly loaded thin wire loops. We analyze power as well as balance between the magnetic and electric responses as functions of the antenna load and size. The loads that maximize the received power are shown to be, in general, different from those that are needed to equalize electric and magnetic responses. The consequences of this for the estimation of the direction of arrival are briefly discussed. Our goal is to construct an EM vector-sensor antenna based on the ideas in this paper, and conduct experiments to confirm the expected advantages of using vector-sensors in real applications such as radar and communications.

Due to the high-dimensionality of hyperspectral data, feature extraction is an important issue in hyperspectral data classification. In [18], we evaluate and compare the performance of the well-known principle component analysis (PCA) and Fisher's linear discriminant analysis (FLD) for hyperspectral data feature extraction. Based on this, we propose a new feature extraction method utilizing the overall geometric shape of a reflectance curve. The new feature extraction method has three advantages. Firstly, it is physically meaningful. Secondly, since the new feature is extracted by exploiting the similarity inherited in the overall geometric shape of hyperspectral data, samples of the same class form compact clusters in the new feature space, and hence accurate classification can be achieved. Thirdly, label information of training samples is not required in our feature extraction procedure. As a direct result,

the new feature is unlikely to overfit training samples.

Airborne SQUID Magnetic Sensing for Ship Detection:

In [19] we introduced methods for detecting the wake of a ship using an airborne SQUID magnetic transducer. Wake induced by motion of vessels may extend for tens of kilometers and exist for hours under certain conditions in open sea. This forms a useful feature for long-range ship detection. Our methods are applicable for passively detecting a ship wake using measurements obtained by an airborne SQUID magnetic transducer that measures the first-order gradients of the magnetic signature induced by the wake. Analytical formulas of wake magnetic gradients were derived to provide guidelines for the airborne detectors. We also derived probability bounds of wake detection for cross-correlation and square-law detectors, which are useful to predict the expected performance.

Antenna Array Processing for Communications:

In [20] we addressed the problem of identifying and equalizing communication channels in the presence of strong co-channel interference (CCI). We considered the interference and noise as colored noise of unknown covariance and exploited the underlying structure and constraints of the transmitted data and channel outputs. The proposed algorithm optimizes a weighted least-squares cost function using an iterative reweighting alternating minimization procedure. Numerical examples were presented and showed that the proposed algorithm is capable of achieving reliable channel identification and equalization in the presence of strong CCI at moderate SNR.

We presented in [21], [22] maximum likelihood (ML) methods for space-time fading channel estimation with an antenna array in spatially correlated noise having unknown covariance; the results are applied to symbol detection. The received signal is modeled as a linear combination of multipath-delayed and Doppler-shifted copies of the transmitted waveform. We considered structured and unstructured array response models, and derive the Cramér-Rao bound for the unknown directions of arrival, time delays, and Doppler shifts. We also developed methods for spatial and temporal interference suppression. Finally, we proposed

coherent matched-filter and concentrated-likelihood receivers which account for the spatial noise covariance, and analyze their performance.

We proposed in [23], [24] finite-length multi-input multi-output adaptive equalization methods for "smart" antenna arrays using the statistical theory of canonical correlations. We showed that the proposed methods are related to maximum likelihood reduced-rank channel and noise estimation algorithms in unknown spatially correlated noise, and to several recently proposed adaptive equalization schemes.

In Discrete Multi-Tone (DMT) systems a cyclic prefix is added to the front of each modulated symbol-frame in order to partition the whole channel into many narrow independent subchannels. When the length of the cyclic prefix is shorter than the channel length, Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI) will occur in the output signal. In [25] we present a Decision Feedback Equalizer (DFE) on a symbol level to deal with this problem. The DFE first removes the ISI. It then recovers the distortion caused by ICI. The advantage of this equalizer is that the cyclic prefix for the equalizer can be discarded thus leads to no bandwidth loss. Several simulation examples are presented to show the significant improvement of the equalized signal over the unequalized.

Acoustic Array Processing:

In [26] we carefully considered the effect of sensor placement on the direction-of-arrival estimation performance of an array of acoustic vector sensors. We derived expressions for the Cramér-Rao bound on the azimuth and elevation of a single source, for an array of arbitrary shape. Using this result, we found necessary and sufficient conditions on the geometry to ensure that the ability to estimate one of the bearing parameters is independent of knowledge of the other. We argued that these conditions provide a compelling criterion for array-shape design. We then considered a bound on the mean-square angular error, which is a very useful single measure of performance in three-dimensional bearing problems. Using this bound, we extended our previous conditions to provide a sufficient set of conditions that ensure the array's optimal performance is isotropic. We also determined that knowledge of the signal and noise powers makes no difference to the optimal ability to estimate the bearing.

In [27] we considered the passive direction-of-arrival (DOA) estimation problem using arrays of acoustic vector sensors located in a fluid, at or near a reflecting boundary. We formulated a general measurement model applicable to any planar surface, derived an expression for the Cramér-Rao bound on the azimuth and elevation of a single source, and obtained a bound on the mean-square angular error (MSAE). We then examined two applications of great practical interest: hull-mounted and seabed arrays. For the former, we used three models for the hull: an ideal rigid surface for high frequency, an ideal pressure-release surface for low frequency, and a more complex, realistic layered model. For the seabed scenario we modeled the ocean floor as an absorptive liquid layer. For each application we used the CRB, MSAE bound, and beampatterns to quantify the advantages of using velocity and/or vector sensors instead of pressure sensors. For the hull-mounted application, we showed that normal component velocity sensors overcome the well-known, low-frequency problem of small pressure signals without the need for an undesirable "stand-off" distance. For the seabed scenario, we also derived a fast wideband estimator of the source location using a single vector sensor.

Most array processing methods require knowledge of the correlation structure of the noise. While such information may sometimes be obtained from measurements made when no sources are present, this may not always be possible. Furthermore, measurements made *in-situ* can hardly be used to analyze system performance before deployment. The development of models of the correlation structure under various environmental assumptions is therefore very important. In [28] we obtained integral and closed form expressions for the auto- and cross-correlations between the components of an acoustic vector sensor (AVS) for a wideband noise field, under the following assumptions concerning its spatial distribution: (i) azimuthal independence; (ii) azimuthal independence and elevational symmetry, and (iii) spherical isotropy. We also derived expressions for the cross-covariances between all components of two spatially displaced AVS's in a narrowband noise field under the same assumptions. These results can be used to determine the noise covariance matrix of an array of acoustic vector sensors in ambient noise. We applied them to a uniform linear AVS array to asses its beamforming capabilities and localization accuracy, via the Cramér-Rao bound,

in isotropic and anisotropic noise.

We derived in [29], [30] fast wideband algorithms for determining the bearing and 3-D position of a target using a distributed array of acoustic vector sensors (AVS's) situated in free space or on a reflecting boundary. Each AVS locally estimates the bearing from its location to the target using a rapid wideband estimator we develop based on the acoustic intensity vector; adaptations of beamforming-based bearing estimators for use with an AVS are also discussed. The local bearing estimates are then transmitted to a central processor where they are combined to determine the 3-D position. Closed-form weighted least-squares (WLS) and re-weighted least-squares algorithms are proposed to achieve this. A bound on the mean-square angular error of the local bearing estimates is obtained, and used along with the data to adaptively determine the weights for the WLS routine. In addition, a measure of potential 3-D location performance for the distributed system is developed based on a two stage application of the Cramér-Rao bound. The results are relevant to the localization of underwater and airborne sources using freely-drifting, seabed, and ground sensors. Numerical simulations illustrate the effectiveness of our estimators and the new potential performance measure. This work has led to a new transition with successful results, see below.

In [31], [32] we proposed an effective adaptive null-forming scheme for two nearby microphones in endfire orientation which are used in many kinds of hearing devices such as hearing aids and noise cancellation in cockpit. This adaptive null-forming scheme is mainly based on an adaptive combination of two fixed polar patterns that act to make the null of the combined polar pattern of the system output always be toward the direction of the noise. The adaptive combination of these two fixed polar patterns is accomplished by simply updating an adaptive gain following the output of the first polar pattern unit. The value of this gain is updated by minimizing the power of the system output and related adaptive algorithms to update this gain are also given in this paper. We have implemented this proposed system on the basis of a programmable DSP chip and performed various tests. Theoretical analyses and testing results demonstrated the effectiveness of the proposed system and the accuracy of its implementation. This work has led to a new commercial transition with successful

results, see below.

Chemical Array Processing for Explosives Detection:

In [33], [34] we developed methods for automatic detection and localization of landmines using chemical sensor arrays and statistical signal processing techniques. The transport of explosive vapors emanating from buried landmines was modeled as a diffusion process in a two-layered system consisting of ground and air. The measurement and statistical models were then obtained from the associated concentration distribution. We derived two detectors, the generalized likelihood ratio (GLR) test and the mean detector, and determined their performance in terms of the probabilities of false alarm and detection. To determine the unknown location of a landmine we derived a maximum likelihood (ML) estimation algorithm and evaluate its performance by computing the Cramér-Rao bound. The results were applied to the design of chemical sensor arrays, satisfying criteria specified in terms of detection and estimation performance measures, and for optimally selecting the number and positions of sensors and the number of time samples. To illustrate the potential of the proposed techniques in a realistic demining scenario, we derived a moving-sensor algorithm, in which the stationary sensor array is replaced by a single moving sensor. Numerical examples were given to demonstrate the applicability of our results.

Array Processing for Biomedical Applications:

In [35] we presented a maximum likelihood method for estimating evoked dipole responses using electroencephalography (EEG) and magnetoencephalography (MEG) arrays, which allows for spatially correlated noise between sensors with unknown covariance. The electric source was modeled as a collection of current dipoles at fixed locations and the head as a spherical conductor. We permitted the dipoles' moments to vary with time by modeling them as a linear combination of parametric or non-parametric basis functions. We estimated the dipoles' locations and moments, and derived the Fisher information matrix for the unknown parameters. We also proposed an ML-based method for scanning the brain response data, which can be used to initialize the multi-dimensional search required to obtain the true dipole location estimates. A goodness-of-fit measure accounting for multiple time snapshots

and correlated noise was introduced. We presented numerical examples of both simulated and real data to demonstrate the performance of the proposed method.

In [36] we derived Cramér-Rao bounds on the errors of estimating a single dipole's location and moment using electroencephalography, magnetoencephalography, and combined EEG/MEG modality. We used realistic head models based on knowledge of surfaces separating tissues of different conductivities, obtained from magnetic resonance (MR) or computer tomography (CT) imaging systems. The electric potentials and magnetic field components at the respective sensors were obtained as functions of the source parameters through integral equations. These equations were formulated for solution by the boundary or the finite element method (BEM or FEM), with a weighted residuals technique. We presented a unified framework for the measurements computed by these methods that enables the derivation of the bounds. The resulting bounds may be used, for instance, to construct the confidence regions in dipole localization, and to choose the best configuration of sensors for a given patient and region of expected source location. Numerical results demonstrated an application for showing regions of good and poor expected accuracy in estimating the source parameters, based on a real EEG/MEG system.

In [37] we analyzed fundamental limitations in estimating the position, orientation and intensity of dynamic brain sources with data from EEG/MEG. We derived the Cramér-Rao lower bound on the covariance of the estimated parameters of a dynamic dipole source. Our results extended previous work on parameter estimation of a fixed brain source through computing the CRB for nonlinear dynamical source models. We performed computer simulations for representative sources, using data of an actual EEG/MEG system and the realistic head model we derived in [36].

We presented in [38] a method for estimating mechanical properties, active stress and passive elasticity modulus, of the *in vivo* heart using 2D magnetic resonance imaging (MRI) tissue-tagging and intra-ventricular pressure measurements. It has been shown that alterations in these properties may pre-date the onset of certain cardiac dysfunctions. We assume that the myocardium's stiffness tensor is non-homogeneous and propose to model

this non-homogeneity using a set of *a priori* known basis functions and the corresponding unknown coefficients. We combine this globally defined physical model with a finite-element formulation and dynamic analysis, and apply non-linear least squares to obtain the unknown parameters (basis functions coefficients.) We evaluate the performance of the proposed estimator by computing the confidence region for the estimated parameters. Numerical examples demonstrate the applicability of our results.

The inverse problem of electrocardiography can be defined as the determination of the information about the electrical activity of the heart from measurements of the body-surface electromagnetic field. The solution to this inverse problem may ultimately improve the ability to detect and treat cardiac diseases early. In [39], we present an algorithm for estimating the current density of the heart using electrocardiography (ECG) and magnetocardiography (MCG) sensor arrays. We model the electrical activity of the heart using current density represented by a set of spatio-temporal basis functions. In order to solve the corresponding Fredholm equation we apply the element-free Galerkin method and compute the measurements as a function of the torso geometry and cardiac source. Then, we maximize the likelihood function to estimate the unknown parameters assuming a presence of spatially correlated Gaussian noise with unknown covariance matrix.

PhD Graduates:

We have graduated (i) Malcolm Hawkes whose work on acoustic-vector sensor processing is summarized in his PhD thesis [40]. He is now a Research Associate with Stafford Trading Inc; (ii) Aleksandar Dogandžić whose work on sensor array processing in correlated noise (for radar and communications) is summarized in his PhD thesis [41]. He has assumed an Assistant Professor position at Iowa State University.

Transitions:

We have applied our analytical results on performance of radar sensor arrays in [2], [3] to the TechSat21 system, in collaboration with Dr. John Garnham [Phillips Laboratory, VTRA, telephone: (505) 846-7224], who provided us with the numerical data for this system. The

purpose of TechSat21 is to estimate direction, range, and velocity of a ground moving target, using an array of microsatellites. We have shown that our results are useful to predict the performance of this system (e.g. accuracy of estimating the above target parameters in terms of Cramér-Rao bounds and ambiguity functions), and to optimally design similar systems.

Our methods using acoustic vector sensors is continued to be pursued by researchers at NUWC in Newport and resulted in a new transition. These researchers have now applied our algorithm in [29], [30] to locate real wideband sources in a lake, with great success. We are collaborating with them on the analysis and simulation of specific scenarios, and provided them with coded algorithms for the processing of their raw measurements and integration into the experimental hardware and act as consultants. The third stage of this (6.3) project was successfully concluded with demonstrations of our techniques in Lake Seneca in May 2001. Specifically, the algorithm we developed in [29], [30] was applied to locate real sources at depth of 300 ft, distance of 80 ft, with 2 vector sensors at a distance of 12 ft, and the results were very good. NUWC is now moving to the next stage (6.4) involving our methods using vector sensors mounted on a submarine. The NUWC project is headed by Dr. Ben Cray [NUWC, Newport, telephone 401-832-8454].

The proposed scheme in [31], [32] of adaptive null-forming scheme for noise cancellation with two nearby microphones, has been included in current hearing-aid products of GN ReSound Corp. These products are available in the world wide market. More details can be obtained from the web site http://www.gnresound.com.

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